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by

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MILLIMETER WAVE TECHNOLOGY AND ITS APPLICATIONS

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ABSTRACT: This article provides the basic features of millimeter wave guidance technology as well as the primary millimeter wave guidance systems and their characteristics. It also analyzes current levels of technology inside and outside China and discusses future prospects of millimeter wave technology and its applications.

KEY TERMS: Millimeter wave, precision guidance, radar, ground guidance

I. CHARACTERISTICS OF MILLIMETER WAVES

Millimeter waves revere to the frequency spectrum of operational wave lengths from one to ten millimeters. This corresponds to operational frequencies between 300 GHz and 30 GHz. The position on the electromagnetic frequency spectrum of millimeter waves is between microwaves and infrared waves. This determines that millimeter waves have both microwave and optical characteristics. Millimeter waves are weakened bv the atmosphere to a much greater extent than are microwaves. There are marked changes in the amount of loss as the frequencies are changed. In general, the higher the frequency the greater the attenuation. However, due to absorption effect of vapors and oxygen, peaks appear at certain frequencies, resulting in especially great attenuation rises around 35 GHz, 94 GHz, 140 GHz and 220 GHz. Another way of putting this is that the areas where there is slight attenuation are called transmission windows. Normally, the operating frequency for millimeter wave detection systems is chosen from among atmospheric transmission windows in order to improve the operational ranges. However, there are some systems, such as secure communications, which use an operational frequency at an area of high attenuation in order to prevent its being listened in on beyond its

designed range. The attenuation due to rain is greater in the millimeter spectrum than it is for microwaves, and is about the same as it is for infrared and optical waves. Clouds, fog, smoke and dust create serious attenuation problems for infrared and optical waves, but have very little effect on millimeter wave transmission. Millimeter wave guidance systems are similar in overall design to microwave guidance systems. However, they are much different in system capabilities. Millimeter wave radars have several potential advantages.

HIGH DEGREE OF PRECISION. With short wavelength, the antenna wave beam is narrow and has high directional precision.

STRONG ANTI-ECM CAPABILITIES. With a narrow wave beam, it compresses the ECM spacial window, and it has a low probability of being jammed. The millimeter wave spectrum jamming power spectrum density is hard to increase, which is advantageous for anti-ECM.

GOOD LOW ALTITUDE AND DOWN LOOKING CAPABILITIES. The narrow wave beam compresses the intensity of the main segment of the complex wave, reducing multiple path signals. Furthermore, in the millimeter wave spectrum, the coarseness of the surface is increased, which can greatly overcome the mirror image effect.

LARGE BANDWIDTH. In the millimeter wave spectrum, when the relative bandwith is not too large, the absolute bandwidth can be very large. Not only can bandwidth wave forms be easily used to provide high distance discrimination, but the frequency zones can be chosen freely, improving the anti-ECM capabilities.

SMALL SIZE. Millimeter wave equipment and systems are small and light, and are suitable for use on tactical missiles and smart weapons.

Due to changes in the battlefield environment, increased ECM and developments in stealth technology, guidance systems are facing new

challenges. If it is necessary to recognize targets and track these targets with precision in complex electromagnetic environments, geographical environments and target environments, millimeter wave guidance systems can meet these requirements and are relatively ideal guidance methods for guided weapons, especially precision guided weapons. There are also some restrictions to millimeter wave guidance. Because of the relatively high attenuation of the millimeter waves in the atmosphere in the transmission process, especially rain attenuation which is markedly higher than for microwaves, this commonly restricts the operational range of millimeter wave guidance. There are many advantages to the system because of the narrow wave beam of millimeter radars. However, for search radars, this makes target acquisition difficult. At times, in order to satisfy the specific requirements of weapons systems, it is paired up with other guidance systems. There are a number of different types of millimeter wave systems: these include the command guidance, ground guidance, wave beam rider guidance and multiple mode and complex guidance. The different guidance methods are different in tactical capabilities. The guidance system should be chosen to correspond to the combat environment and type of target.

II. TYPES OF MILLIMETER WAVE GUIDANCE

1. MILLIMETER WAVE COMMAND GUIDANCE. The basic composition and operational process of the millimeter wave command guidance systems are shown in illustration one. The millimeter wave radar detects and tracks the target, and at the same time keeps track of the missile. It also forms guidance orders in accordance with certain guidance rules which are sent tot he missile through transmission channels. The command receiving equipment provides the control signals and adjusts the flight of the missile. The composition and operational process of the system are the same as for ordinary radar command guidance. The primary special characteristics are its good low altitude capability and the precision of its guidance.

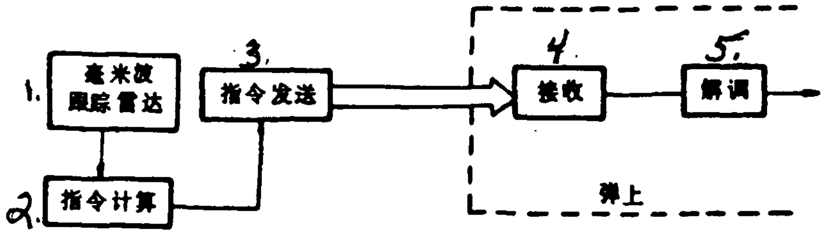

ILLUSTRATION ONE: BASIC COMPOSITION OF MILLIMETER WAVE COMMAND CONTROL
1. Millimete/r wave tracking radar. 2. Command Calculating. 3. Command transmission. 4. Receiving. 5. Demodulation.

Low altitude capabilities are primarily affected by two factors. These are complex wave interference and the multiple channel effect. The basic method of suppressing the complex wave is to reduce the radar "area" of the radar's range discriminating element while ensuring receipt of the target signal. Normally, non-phase parameter radars can only discriminate between two spacial dimensions and one range dimension. Phase parameter radars, however, in addition to the above mentioned discriminations can also discriminate speed, thus greatly reducing the "area" of the discrimination element. Therefore, the phase discrimination radar low altitude capabilities will be superior to non discrimination radars. Millimeters radars have high spacial discrimination, high doppler sensitivity and can achieve super wide bandwith wave formation, obtaining extremely high ranging discrimination, complex wave power can be effectively suppressed, allowing the target signal power in the discrimination element to be greater than the power of the complex wave. In low altitude detection, the multiple channel signal often can enter the receiving antenna through at relatively high gain levels. Millimeter wave radars can prevent this phenomenon. When detecting moving targets, there is a difference between the multiple channel signals and the direct signal doppler frequency shift. Because millimeter waves are short, this type of difference will be large be large enough. The receiver and the signal processor can filter out the multiple channel signal from the complex

signal. The millimeter wave radar strong low altitude detection capability has been demonstrated through a large number of experiments. It can be widely used in weapons systems.

Command guidance operational ranges are primarily determined by the detection range of the millimeter radar.

The use of low noise receiving equipment such as HEMT (high electron migration transistor) can improve the system sensitivity. The use of power synthesis to increase the solid state sender is a technology currently under development. There has been successes with multiple channel synthesis technology in the circuitry, with a effectiveness of as much as 90 percent. As the wave forms become complex, the frequency band is expanded and with synthesis of circuitry power, more and more difficulties will be confronted. Space synthesis technology is already under serious consideration. As microelectronic technology is developed and as the uniformity and amplitude and controllability of active elements continues to be improved, an excellent foundation for space synthesis is being laid, and is promoting research in millimeter wave phase controlled array radar.

2. MILLIMETER WAVE HOMING GUIDANCE. Millimeter wave homing guidance is a primary method of precision guidance. Millimeter wave radars are small, light, suitable for installation on missiles, sub weapons or artillery shells. This type of guidance is characterized by: target detection and command formation are both on the missile or shell and it has strong independent capabilities. Search guidance is more precise than that of control guidance. Under conditions of certain goneometric error, linear deviation error is gradually reduced, detection coordinate systems and ballistic coordinate systems are closely related. Furthermore, commands need not be transmitted long distance, so they will not lead to distortion, interruptions or interference. The special problems which exist in search guidance are the near field large target effect and the antenna shield error. As the missile approaches the target, the stereo

angle occupied by the target gradually increases. Because of coherent effect of the multiple scatter center, there is a change in the equivalent phase for the scatter signal, forming angular noise interference. When this interference is serious, it can cause the steering probe to track in a direction away from the target. By using wide bandwith signals, the different frequency; component angle noise have a certain mutual damping effect, and an active radiometer can be selected and it is possible to switch over to radiometer passive search at the terminal phase. Most radiometers operate in a bandwidth reception mode. The steering head target tracking process, because the antenna sweeps in relation to the antenna shield, a change in the refraction will result in error. At the same time, when a coupling link is formed between the measurement coordinate system and the ballistic movement, the antenna shield can cause an energy loss. The basic point of departure in designing antenna shields is the selection of material and the thickness of the walls so the different frequencies within the bandwidth will have slight attenuation and phase distortion at different angles. When selecting he material for the antenna shield, it is also necessary to meet the requirements for mechanical strength. This must obtain the optimum trade-off. However, errors always exist. When the system requires very high standards, it is possible to use computer compensation. The precision requirements for millimeter wave antenna shields are much stricter than those for microwave antenna shields. It is extremely important to find a material with a low dielectric constant. Millimeter wave homing includes three basic types: active homing, semi active homing and passive homing.

(1). Millimeter wave active homing guidance. Compared to microwave active homing guidance, the major difference is that it has strong low altitude and down looking tracking capabilities. The most typical application of millimeter wave active homing is against armored targets or against vital surface targets. It requires that the steering probe detect moving or stationary targets against a background of highly complex waves. This is the key to the millimeter wave active homing. This type of steering probe has the capability to lock on after sending

and to send and forget. Against armored targets, millimeter wave wide band linear frequency modulation carrier wave (FMCW) steering probe basic composition and operational modes are shown in illustrations two and three.

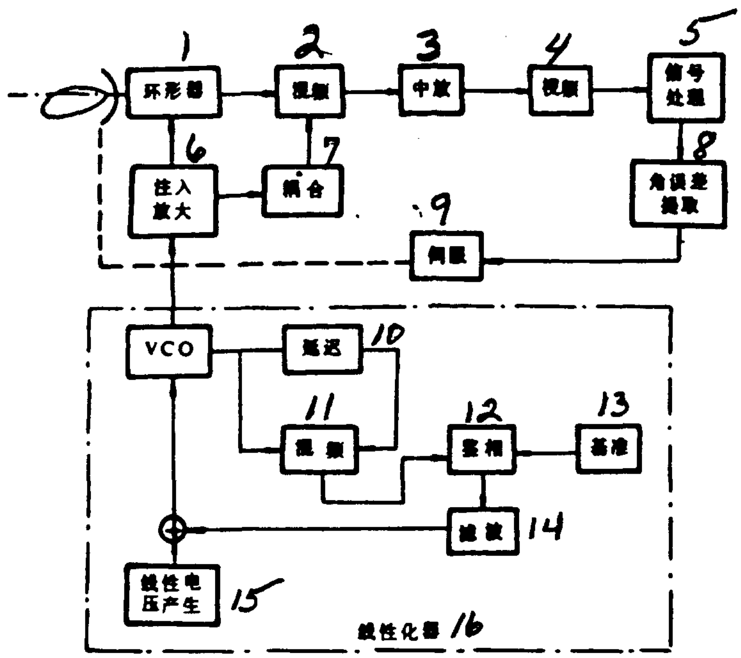

ILLUSTRATION TWO: FMCW ACTIVE STEERING PROBE DIAGRAM

1. Circulator. 2. Frequency mixer. 3. Intermediate amplifier. 4. Video frequency. 5. Signal Processing. 6. input amplification. 7. coupling. 8. Angular error extraction. 9. Servo. 10. Delay. 11. Frequency mixing. 12. Phase detection. 13. Reference. 14. Wave filtering. 15. Linear voltage generation. 16. Linearizer.

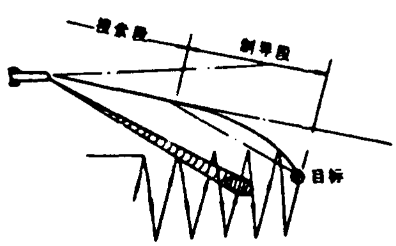

ILLUSTRATION THREE: MILLIMETER WAVE ACTIVE HOMING GUIDANCE ANTI-ARMOR OPERATIONS MODE

1. Search sector. 2. Guidance sector. 3. Target

When attacking down and attacking, the antenna main segment strikes the ground, and under normal circumstances, the complex wave power of the main segment is much greater than that of the target, and the ranging and frequencies measure the target with no differences. The major threat is a false alarm caused by the complex wave. When the complex wave to noise ration (C/N) is greater than one, it is effective to increase discrimination. When selecting sending power, receiver sensitivity and discrimination, the trade-off principle is to make every attempt to have C/N equal to one.

The FMCW wave form has excellent capabilities. Anti-armor millimeter wave active homing usually uses this system. The surface or the target return wave signal frequencies are mixed with those of the sending signals, and the differential beat frequency represents the range of the target. With a narrow band wave filter, ranging discrimination is improved. With matching wave filtering, the ideal linear FM wave ranging discrimination can be expressed by (a) $\Delta R = \frac{c}{2} \cdot \frac{T}{T-\tau} \cdot \frac{1}{\Delta F}$ where c is the speed of light, upper case tao is the repeat cycle, lower case tao is the return wave delay and deltaF is the width of the FM band.

Through 通常 $\tau \ll T$, $\frac{T}{T-\tau} \simeq 1$, 距

the range discrimination is determined by deltaF, and the complex frequency area is shown in illustration four.

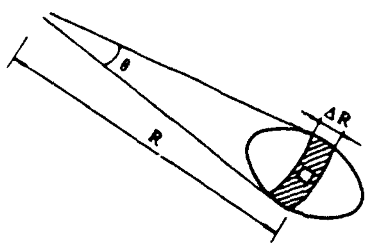

ILLUSTRATION FOUR: AREA OF HIGH RESOLUTION DOWN LOOKING COMPLEX WAVE

The non-linear characteristics which exist in the actual circuitry reduce the ranging discrimination and the improvement of the FMCW wave form FM linearality is an important key technology. The use of open loop precompensation methods to improve the linearality of high frequencies is limited. Normally it can only reach around one percent, and cannot satisfy requirements. Closed loop correction methods use wave detection for real time continuous monitoring of the ratio, forming control signals and making real time correction to the voltage control oscillator (VCO) making high linear indexes possible.

Using a pulse system, there is good separation of receiving and sending and simple wave form but the peak power is high and during low altitude detection or diving attack, it requires a narrow pulse transmission as well as the use of pulse compression, and after processing the pulse code width is in the range of one to two nanoseconds.

When diving to attack the target, no matter what wave form is used, the signal-to-noise ration (S/C) is related to the diagonal distance R, and the larger R, the lower the signal-to-noise ration. In order to ensure that the effective operational range R is not increased and the firing range is not reduced, new types of flight paths use low level flight, doing down looking horizontal search while flying, which is the "illuminated runway" type (Flare) flight path. In the target search process, the diagonal distance R is basically maintained and does not change, which can effectively ensure the signal-to-noise ration. When the target is detected, it switches over to tracking, and diving to attack the target.

Another important key technology in millimeter wave active homing system designs is target recognition. This is a prerequisite for effectiveness in an air-to-ground missile. It requires research into the special characteristics of the target, special characteristics of the background, and the combat background is not always the same, so target recognition is a complex technology and is very difficult. If a single

observation exceeds the constant false alarm limit, this is called the first threshold. Further accumulations raising the detection possibility is called the second threshold. When the second threshold is crossed it is still possible to have a false target create a false alarm. It is necessary to establish a determination threshold based on target recognition which could be called the third threshold. The criterion for establishing the third threshold is the extraction of special target characteristics. This is the route to effective technology for target recognition. The antenna lock system of the steering probe sends out a pair of orthogonally polarized waves which may be vertically and horizontally polarized or may be left and right turn polarized. There must also be corresponding complete orthogonally polarized reception to detect he amplitude phase signals of various components and process them.

(2). Millimeter wave semi-active homing guidance. In semi-active homing, the sending and receiving are separated and it is a double station operation. The radar transmitter is set up on the surface or on another platform to irradiate the target. The steering probe receives the signals scattered by the target and tracks it and gives out orders to correct the missile's flight. The basic composition of semi-active homing is shown in illustration five.

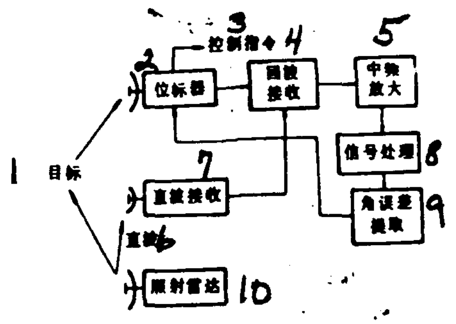

ILLUSTRATION FIVE: DIAGRAM OF MILLIMETER WAVE SEMI-ACTIVE HOMING GUIDANCE

1. Target. 2. Position marker. 3. Control commands. 4. Return wave reception. 5. intermediate amplification. 6. Direct wave. 7. Direct wave reception. 8. Signal processing. 9. angular error extraction. 10.

irradiation radar.

The characteristics of millimeter wave radar semi-active guidance are that the missile carries the sender, it is relatively simple, is low cost, does not radiate energy and has good concealment characteristics. The irradiation radar is not limited by the space in the missile, so it can have high radiation power and antenna gain, so semi-active homing has a long operational range. This type of system is lock-on before firing and no disengage after firing type of guidance system. It is generally used for single target intercept. Typical targets for millimeter wave semi-active homing intercept are super low altitude aircraft and cruise targets. Against this type of targets, continuous irradiation is normally used. The missile uses inverted reception, narrow band tracking and moving target processing. Because it uses the millimeter wave band, there is a marked doppler effect. When it is able to see them, it can also intercept tanks attacking on the surface.

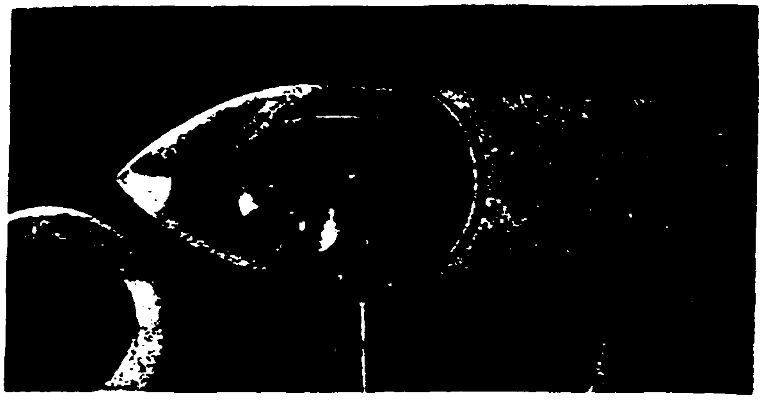

ILLUSTRATION SIX: Ka WAVE BAND CONTINUOUS WAVE SEMI-ACTIVE GUIDANCE PROBE

Illustration six is the Chinese designed Ka wave band continuous wave semi-active steering probe. It has anti-super low altitude target and anti-tank capabilities. This steering probe uses a quasi-back feed type of feed source and a parabolic reflector surface coupled with a power gyroscope to achieve a conical sweep. The antenna direction and the missile have excellent uncoupling capabilities. The antenna shield is shaped like a pointed cone and is made of composite organic material. It

has good mechanical properties, high permeability, and very low aiming error and deviation, satisfying design requirements. The antenna shield is shown in illustration seven. The forward end of the receiver uses hybrid integrated circuitry. The forward return wave receiver and the rear direct wave lock phase receiver are integrated onto single microchips, see illustration eight.

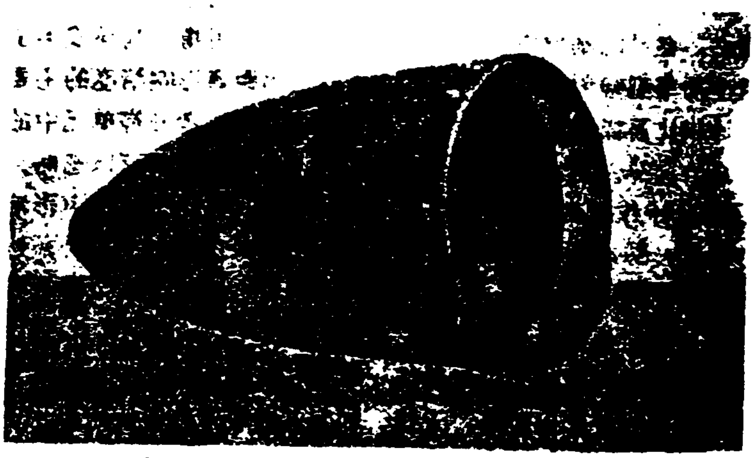

ILLUSTRATION SEVEN: Ka WAVE BAND CONTINUOUS WAVE SEMI-ACTIVE PROBE ANTENNA SHIELD

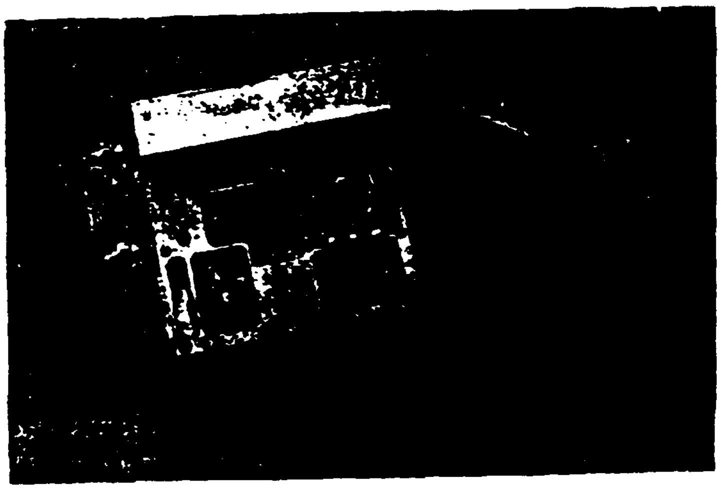

ILLUSTRATION EIGHT: FRONT END OF kA WAVE BAND PROBE MIXED ASSEMBLY. (INCLUDES FORWARD RECEIVER, REAR RECEIVER, POWER SOURCE SYSTEM, CONSTANT

TEMPERATURE SYSTEM AND VOLTAGE CONTROL OSCILLATOR CIRCUITS.)

(3). The millimeter wave radiometer passive homing. The millimeter wave radiometer passive homing is set up on the basis of detecting the heat radiated by the target and the background. It extracts information based on the difference between the temperature radiated by the target and its surroundings and tracks the target. This type of system is highly precise and locks onto the target's center-of-mass. During homing guidance, it normally may use a full power type radiometer, which is quite a bit simpler than the Dicke radiometer. Its basic composition is shown in illustration nine,

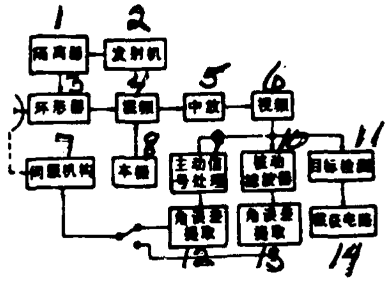

ILLUSTRATION NINE: DIAGRAM OF COMBINED PRINCIPLES OF ACTIVE HOMING AND RADIOMETER PASSIVE HOMING

1. Isolator. 2. Sender. 3. Circulator. 4. Frequency mixer. 5. Intermediate amplifier. 6. Video frequency. 7. Servo mechanism. 8. Local oscillator. 9. Active signal processing. 10. Passive wave filter. 11. Target detection. 12. Angular deviation extraction. 13. Angular deviation extraction. 13. Acquisition circuitry.

The operational range of the radiometer is related to the capabilities of the antenna, the special nature of the target and the background, the capabilities of the radiometer and the signal-to-noise ratio of detection. With a fixed target and background, an expanded intermediate amplifier bandwidth, reduced noise coefficient and higher antenna gain it is possible to increase the operational range. When the antenna gain is increased, the wave beam width is reduced, and the target wave beam duty factor is increased. During stable tracking, ordinary wave beam duty factors are about ten percent. In addition, the longer the time

of integration, or the narrower the band pass of the low power amplifier, the better for increasing the operational range. During the design of the conical sweep passive radiometer system, the time the target remains in the wave beam should satisfy the time of integration requirements, otherwise, it will result in reduced sensitivity.

Passive radiometer homing uses wide band operations, has good angular noise to signal correlation, is simple and reliable, is low cost, has good operational concealment, and has a relatively operational range. The typical applications are in precision guided weapons direct hit targets, terminal homing or used in the sensing probe of smart weapons. Precision guided weapons can use control guidance or semi-active homing in the initial and intermediate stages. The primary factor affecting the precision at long distances is the noise or remaining complex wave in the discrimination elements, so angular noise can be disregarded. As the range becomes shorter and shorter, the thermal noise effects become less and less, and the effects of angular noise increase. When the two effects become equal, it is switched over to passive radiometer homing.

Radiometers used in smart weapons act as terminal sensing equipment so the shell or bomblet or other conventional weapon becomes guided. Typical examples are the United States Army sense and destroy armor (SADARM) which is equipped with a shell with a radiometer. When this shell flies over the target area, it opens a parachute so the shell follows a spiral course searching the surface of the ground. Once it detects a target, it quickly gives the command, and it ignites the self-forging warhead, and high speed pellets strike the armored target. According to calculated results, this type of weapon is relatively highly cost effective, and it is being given widespread serious considerations. Millimeter wave radiometers must undergo shocks of more than 10,000 g (translator's note: probably grams). Integration not only allows for it to be smaller, it also provides good shock resistance capabilities.

The semi-active radiometer sends out wide band noise and receives

scattered signals from the target and the background. Its capabilities are similar to the passive radiometer. The difference is that it uses differences between the target and the background scatter systems to extract information. Its operational range is greater than that of the passive radiometer.

3. MILLIMETER WAVE WAVE BEAM RIDER GUIDANCE. This type of guidance uses wide band beam radar to acquire the target and then narrow band beam millimeter radar for tracking. This ensures that the axis of the narrow band beam is pointed at the target, and also forms wave beam encoding. In the tail of the missile are installed receiving equipment, which receives and decodes the coding, and forms the orders on the missile to control the missile in its flight along the axis of the wave beam. Millimeter wave radar wave beams can be very narrow and multiple channel noise interference is very slight. Beam rider is very precise. It has better all weather capabilities than laser beam rider guidance. It can operate in smoke, fog and dust. Millimeter wave beam rider precision is about the same as that of millimeter wave command guidance. The difference is that beam rider guidance commands do not need to be sent along transmission channels, but are formed on the missile. Against super low altitude targets and against armored targets, the millimeter wave beam rider system ideal structure should be: The entire system should operate independently. It should have strong decision making capability. It should be vehicle mounted. The system coefficient selections are in general:

Antenna diameter:	0.5 meters
Capture wave beam	six degrees
Tracking wave beam	0.2 degrees
Operating Frequencies	180 GHz (capture)
	220 GHz (tracking)
Operational range	five kilometers
Search Range	five degrees by 25 degrees
Search time	less than ten seconds
Missile data rate	50 Hz

Missile data rate 50 Hz

4. DOUBLE MODE GUIDANCE. The more and more complex combat environment, intensified resistance, and the development of stealth technology pose a serious threat to missile systems. Double mode or multiple mode homing guidance is an advance design idea of the past few years. It uses two or more types of electromagnetic frequency spectrums to detect and track at the same time and has the advantages of the two types of electromagnetic frequency spectrums. It has excellent target recognition capabilities and anti-stealth capabilities. Millimeter wave and infrared imagery double mode homing guidance reflects the level of the current new generation guidance technology.

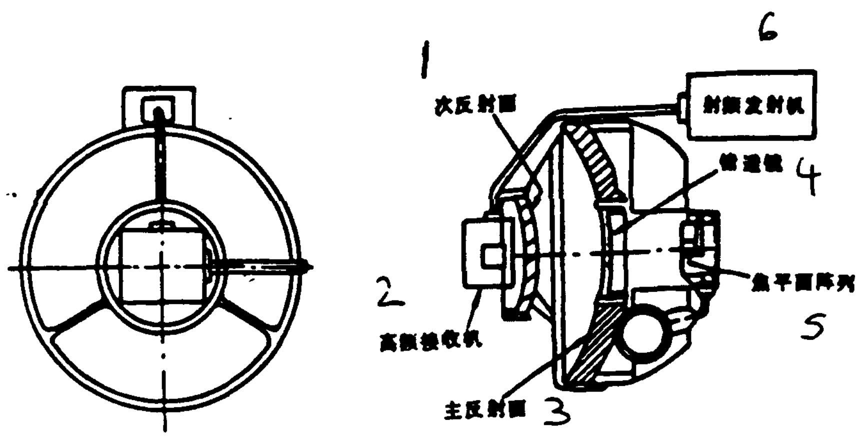

ILLUSTRATION 10: INFRARED MILLIMETER WAVE COMMON APERATURE PROBE
1. Secondary reflective surface. 2. High frequency receiver. 3. Primary reflective surface. 4. Germanium lens. 5. Focal Plane Array. 6. Radio frequency transmitter.

Millimeter wave infrared double mode guidance can use separate apertures or can use the same aperture. Separate aperture systems refer to the high frequency portion of millimeter wave and the infrared optical circuits being independent. The design is not very difficult, but relatively speaking, it takes up more space and it can easily be restricted by the carrier during use. The common aperture requires a unified composite design for the optical circuit and the high frequency

portion of the millimeter waves. The overall design is compact, and the field of view of the two frequency spectrums match up closely. The technology is very difficult. Illustration ten shows the common aperture system. The millimeter wave uses front feed and the infrared imaging system uses rear feed. The millimeter wave antenna primary reflective surface is the main infrared lens. The germanium lens at the center portion of the main surface reflects millimeter waves and infrared rays pass through. The secondary surface allows the millimeter waves to pass through but reflects infrared rays. With both these wave bands operating, it is also able to make its own selections in the actual environment, so the homing is in the optimum "mode". This type of double mode steering probe is suitable for attacking expensive targets. The SADARM which is currently being developed has progressed from its original millimeter wave sensing to millimeter wave infrared double mode sensing. The revolving missile (RAM) uses separate aperture double mode homing, radar type microwave phase comparison angle measurement, uses pole shaped antennas on either side, and in the middle is an infrared steering probe antenna feed system which does not affect the infrared optical circuit transmission and is passive homing. The millimeter wave and infrared common use aperture steering probe is currently in the development stage. The NATO MSOW uses this type of homing.

Millimeter wave guidance technology is not only being more widely applied to precision guided weapons and smart weapons, but it is also used in strategic defense planning, with the objective of indirect aiming launch, lock on after launch, and launch and forget. Attention is being paid to high effect feedback ration, requiring it be capable of being produced and purchased.

Developments in microelectronics will create far reaching affects in millimeter wave guidance. Single chip integrated circuits using GaAs materials have low noise, are resistant to low temperatures and are super fast. This will allow the guidance system to have greater sensitivity, be smaller, more reliable, signal pre-processing can reach 500 million times

2per second, signal processing 50 million times per second, data processing can reach five million times per second, greatly improving the level of intelligence of the guidance system. In millimeter wave guidance technology, it is predicted that there will be energetic developments in imaging guidance, multiple mode guidance and composite guidance. Millimeter wave phase controlled array radar technology has been placed on the agenda. This will bring tremendous changes to surface radars as well as radar on missiles.

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